University of Maryland
Agricultural Experiment Station

Bulletin No. 345 March, 1933

# PART I. THE MOSAIC DISEASE OF TOMATOES

By J. W. Heuberger and J. B. S. Norton.

## INTRODUCTION

Tomato mosaic has been reported from Europe, Australia, Canada and the United States, and it is probably world-wide in its distribution. In 1922 it had been reported from at least twenty-three states. In Maryland the disease is found wherever the tomato is grown.

The losses caused by the mosaic disease in Maryland for the years 1928, 1929, and 1930 have been slight; a 1 per cent loss being reported in 1928 and 1929, and a 0.5 per cent loss in 1930. The average losses throughout the United States for the same period have also been relatively slight, but some states have reported a loss of seven and eight per cent. Although the disease may cause only a slight loss to the crop as a whole, the damage on individual farms and in individual fields may be very severe. If infection occurs at transplanting time the loss in individual fields may run as high as 50 per cent.

Mosaic was first reported on tomatoes by Woods (39) in 1902, and he recognized it as a disease very similar to tobacco mosaic. Tomato mosaic was observed under field conditions in Connecticut by Clinton (7) in 1907. In 1908 Clinton (8) showed that the mosaic of tomatoes was transmissible to tobacco and vice versa. Westerdijk (38) reported in 1910 that the mosaic disease of tomatoes was readily transmissible by inoculation, and that it was seed borne. In 1914 Norton (31) reported that the mosaic disease of tomatoes had only been noticed extensively in Maryland for the previous two or three years, it first being reported in 1910. Allard (1) in 1914 showed the importance of aphids to the transmission of the disease, and in 1916 he (2) proved that the disease was not seed borne. A great deal of work which has been done on this disease since 1916 will be mentioned in the following pages.

## CAUSE

The mosaic disease of tomatoes belongs in the group of diseases known as "virus diseases". The term "virus" as now used in relation to plant diseases is understood to mean a filterable agent or principle which has the power of inducing the disease. The nature of the virus is unknown. However, the properties of the virus are well known (37). It will pass thru filters that will keep back bacteria; it is still infectious after being diluted to 1-10,000; it retains its infectiousness for over a year when kept at room temperature, after heating for ten minutes at 80° Centigrade and after being treated with alcohols ranging in strength from 33 to 95 per cent for one hour. The thermal death point lies between 85° and 90° Centigrade. These properties are identical with the properties of the tobacco mosaic virus.

The filterable virus theory was first advanced by Beijerinck (4) in 1898, and he demonstrated by experimentation that sap extracted from mosaic tobacco plants was still infectious to healthy plants after being passed thru filters that would keep back bacteria. While a great deal of work done on filtering sap extracted from mosaic plants thru various filters supports Beijerinck's theory the evidence secured does not preclude the possibility that the infective principle is a living organism of very minute size. The fact that the virus has the ability to increase in quantity, as evidenced by the fact that the sap extracted from a plant inoculated with a virus extract diluted to the limit of effectiveness can be diluted to the same degree and still produce infection, suggests the possibility that the virus is a living organism.

## SYMPTOMS OF MOSAIC

Mosaic diseased tomato plants exhibit a variety of symptoms, the most common of these being stunting of the plant and mottling of the foliage. The stunting effect is very marked on early infected plants. The first noticeable symptom on plants in the field, and on old plants in the greenhouse, is that the young apical leaves are bunched and do not unfold as in uninfected plants. When these leaves unfold they have a mottled appearance due to the presence of light and dark green areas. Under field conditions leaves that have been affected for some time may become puckered or very crinkled. The symptoms on the fruit are quite variable. Elevated areas of irregular size and shape occur. These soon become dry and sunken and gradually turn brown and cracking of the skin results due to the growth of the fruit. In some cases practically the whole surface of the fruit is covered with dry, brown or yellow, irregular sunken streaks. Fruit symptoms are not common in Maryland tomato fields and may be due to some other virus than the tomato mosaic virus.

Various degrees of leaf malformations are also found on affected plants. For descriptive purposes these malformations may be divided into three groups although all degrees of variation between these exist. Group 1: Those in which the edges of the leaf are sharply and deeply toothed. A crepe-like appearance of the surface is often associated with this. (Fig. 2, right). Group 2: Those in which the leaf has numerous small leaflets or lobes resembling certain fern leaves. (Figs. 1, C, and 2). Group 3: Those in which the leaf tissue is reduced to a narrow strip along the mid-rib. (Figs. 1, D, and 2, left). These leaf malformations are not common under Maryland field conditions but are common in the greenhouse when young plants are inoculated.


FIG. 1. *Mosaic symptoms on potato-leaved tomato. A. Healthy leaf. B. Crepeing. C. Fern-leaf. D. Filiform-leaf.*

Woods (39) and Allard (2) picture such leaf malformations as in Groups 1 and 3. Westerdijk (38) also pictures and describes the same types of leaf malformation. Various names have been used to describe these two groups of symptoms, such as: filiform-leaf, shoe-string leaf, tendril-leaf and rat-tail leaf, but they properly apply only to Group 3. Of these terms "filiform-leaf" is probably the best. No real descriptive term for Group 1 has been

found. Such terms as savoying, blistering, crinkling and crepeing have been used but they are only descriptive of the surface. As the edges of the leaf are very incised the term "cut-leaf" is proposed. Mogendorff (30) used the term "fern-leaf" for Groups 1 and 3. However, as Humbert (19) had already used this term for Group 2 it should be restricted to this type of leaf malformation. The term "polypinnate-leaf" was used by Mogendorff (30) for Group 2.

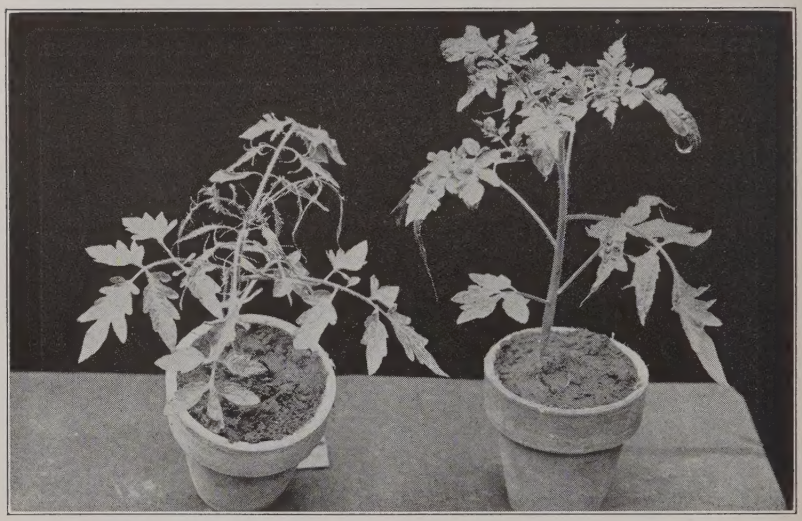


FIG. 2. *Mosaic symptoms on the Marglobe variety. Left. Normal leaves below; malformed leaves above. Right. Cut-leaf, with savoying, on lower right leaf; upper right leaf shows fern-leaf at base; the other upper leaves are of the usual mottled type.*

## DEVELOPMENT OF MOSAIC SYMPTOMS

During the month of October, 1929, tomato plants of various ages were inoculated with tomato mosaic virus from different sources. When these plants were examined it was found that the young plants had filiform symptoms while the old plants had mottled symptoms. Later examinations showed that the plants having filiform leaves had mottled symptoms on the new growth. This change in type of symptom was so interesting that experiments were conducted to determine the factors influencing mosaic symptom development. In all but one experiment (with Bonny

Best), plants of the Marglobe variety were used. The virus used, to all appearances, was the ordinary field type of tobacco mosaic. Except where stated the work was done in the greenhouse.

### Preliminary Experiments

**First Experiment:** Seed was planted on Nov. 9, 1929. Ten plants were inoculated at each age, viz: 1, 3, 5, 7, 9, 11, 14, 18, 21 and 28 days old. On the date of the last inoculation the second leaves were fairly well developed. Seventy-one of the inoculated plants became infected; there being at least 4 in each inoculation. All these showed filiform leaf as the first symptom. Forty-eight of these plants were carried on to trace the development of the symptoms. Twenty next produced fern-leaf, while 28 showed mottling as the next symptom. The 20 plants that produced fern-leaf next produced mottling symptoms. After a plant once produced mottling symptoms it continued to do so, no filiform or fern-leaf again appearing.

**Second Experiment:** Eight plants were inoculated on each of the following dates: On Feb. 15, 1930, when the cotyledons were a half inch long; on March 15 when the second leaf was a half inch long, and on April 4 when the third leaf was a half inch long. Of the plants inoculated on Feb. 15 seven produced filiform-leaf as the first symptom and 5 of these next produced fern-leaf. Of the plants inoculated on March 15 seven showed cut-leaf as the first symptom and one of these next produced fern-leaf. All of the plants inoculated on April 4 showed mottling as the first and only symptom.

**Third Experiment:** Ten plants were inoculated on each of the following dates: On May 14, 1930, when the plants were in the cotyledon stage; on May 19 when the plants were producing the first leaf, and on May 26 when the second leaf was just developing. All of the 30 plants inoculated became infected. They all showed mottling as the first and only symptom.

**Discussion of Results:** The results of the first two experiments indicate that when very young plants are inoculated during the winter months the first symptom of mosaic is usually filiform-leaf. Many of the plants that show this symptom produce fern-leaf on the new leaves formed, and these same plants then produce mottling on the next leaves formed. When a plant once produces mottling symptoms it continues to do so and there is no change in the form of symptom expression. The third experiment was conducted at a time when the days were longer, the temperature higher and the intensity of the light stronger than in the first two experiments. The fact that no leaf malformations occurred indicates that they occur only on very young plants during a period of short day length, low temperature and low light intensity.

## Further Experiments

**Summer Experiment, 1930:** This experiment was conducted to determine the effect on the development of symptoms of shortening the day length. Sixty plants having their second leaf approximately one-fourth inch long were divided into the following groups of 15 plants each: Complete day group,—plants left outdoors continually; Eight hour day group,—plants outdoors from 8:30 a. m. until 4:30 p. m.; Four hour day group,—plants outdoors from 12:30 p. m. until 4:30 p. m.; Two hour day group,—plants outdoors from 2:30 p. m. until 4:30 p. m. The plants were inoculated on Sept. 12 and placed in a light proof cellar. Beginning Sept. 13 the plants were exposed outdoors daily for the given lengths of time and were then returned to the cellar. On Sept. 25 eleven of the complete day group showed mottled symptoms and 4 showed cut-leaf symptoms; 6 of the eight hour day group showed cut-leaf symptoms; 8 of the four hour day group showed cut-leaf symptoms, and all of the plants in the two hour day group were dead. No definite filiform-leaf symptoms were observed. On Oct. 1 measurements were made on the portions of the leaves that were most deeply and sharply toothed, the length of the tooth and width at its base in millimeters being measured. Ten readings were made in each group and these were averaged. They are expressed below as the ratio of the length to the width. Complete day group, 2.4-1; eight hour day group, 3.4-1; four hour day group, 3.7-1. During this experiment the temperatures were as follows: Cellar, maximum 72, minimum 68, average daily 70; outdoors, maximum 90, minimum 64.6, average daily 72.3.

**1930-31 Series:** Seed was planted the first day of each month from October to May, inclusive. Four inoculations were made in the plants of each month's series; inoculations being made when the cotyledons, the first leaf, the third leaf, and the fifth leaf were one-half inch long, respectively. The plants in each month's series were kept separate and were inspected for a sufficient length of time to trace all the stages of symptom development. Records of the temperature and solar radiation were also kept.

The results are presented in the following table:

TABLE 1. EFFECT ON TYPE OF SYMPTOM DEVELOPMENT OF INOCULATING YOUNG PLANTS AT VARIOUS STAGES OF GROWTH AT DIFFERENT TIMES OF THE YEAR

| Time of inoc. | Series | No. inoc. | No. infected | First Symptom | | | Next Symptom | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Filiform-leaf | Cut-leaf | Mottling | Fern-leaf | Cut-leaf | Mottling |
| Cotyledons ½" long | Oct. | 12 | 12 | 12 | 0 | 0 | 12 | 0 | 0 |
| | Nov. | 16 | 13 | 13 | 0 | 0 | 11 | 0 | 2 |
| | Dec. | 15 | 15 | 15 | 0 | 0 | 15 | 0 | 0 |
| | Jan. | 15 | 14 | 14 | 0 | 0 | 13 | 1 | 0 |
| | Feb. | 15 | 15 | 10 | 5 | 0 | 4 | 6 | 5 |
| | March | 15 | 8 | 8 | 0 | 0 | 4 | 0 | 4 |
| | April | 15 | 14 | 2 | 12 | 0 | 2 | 0 | 12 |
| | May | 15 | 15 | 0 | 1 | 14 | 0 | 0 | 1 |
| First leaf ½" long | Oct. | 12 | 12 | 0 | 6 | 7 | 0 | 0 | 6 |
| | Nov. | 16 | 13 | 13 | 0 | 0 | 2 | 11 | 0 |
| | Dec. | 15 | 14 | 0 | 0 | 14 | 0 | 0 | 0 |
| | Jan. | 15 | 12 | 9 | 3 | 0 | 3 | 6 | 3 |
| | Feb. | 15 | 14 | 0 | 0 | 14 | 0 | 0 | 0 |
| | March | 15 | 15 | 1 | 0 | 14 | 0 | 0 | 1 |
| | April | 15 | 15 | 0 | 0 | 15 | 0 | 0 | 0 |
| | May | 15 | 15 | 0 | 2 | 13 | 0 | 0 | 2 |
| Third leaf ½" long | Oct. | 12 | 10 | 0 | 0 | 10 | 0 | 0 | 0 |
| | Nov. | 16 | 14 | 14 | 0 | 0 | 0 | 8 | 6 |
| | Dec. | 15 | 15 | 0 | 15 | 0 | 0 | 0 | 15 |
| | Jan. | 15 | 10 | 0 | 0 | 10 | 0 | 0 | 0 |
| | Feb. | 15 | 12 | 0 | 0 | 12 | 0 | 0 | 0 |
| | March | 15 | 14 | 0 | 0 | 14 | 0 | 0 | 0 |
| Fifth leaf ½" long | Oct. | 12 | 11 | 0 | 0 | 11 | 0 | 0 | 0 |
| | Nov. | 16 | 16 | 0 | 16 | 0 | 0 | 0 | 16 |
| | Dec. | 15 | 15 | 0 | 15 | 0 | 0 | 0 | 15 |
| | Jan. | 15 | 9 | 0 | 0 | 9 | 0 | 0 | 0 |

The data in the above table brings out several interesting points. Fern-leaf symptoms appeared only on plants inoculated when the cotyledons and first leaves were one-half inch long. Almost all of the leaf abnormality symptoms occurred on plants inoculated during the months of November, December and January.

The data on the temperature and the index of solar radiation are presented in the following table:

TABLE 2. AVERAGE MAXIMUM, MINIMUM AND DAILY TEMPERATURES, AND THE AVERAGE DAILY INDEX OF SOLAR RADIATION FOR THE 1930-31 SERIES

| Month | Average Temperature | | | Index of Solar Radiation* (In cc.) |
|---|---|---|---|---|
| | Max. | Min. | Daily | |
| October | 81 | 55 | 68.0 | ..... |
| November | 73 | 58 | 65.5 | ..... |
| December | 74 | 59 | 66.5 | 1.850 |
| January | 77 | 59 | 68.0 | 2.184 |
| February | 78 | 56 | 67.0 | 2.793 |
| March | 79 | 57 | 68.0 | 2.743 |
| April | 82 | 57 | 69.5 | 4.475 |
| May | 86 | 58 | 72.0 | 4.859 |

*Determined by the use of the Livingston Radio-atmometer. It is the amount of evaporation from the black bulb that is due to the action of light.

A study of the above table in conjunction with Table 1 will show that the development of leaf abnormalities is apparently correlated with the amount of solar radiation and not with the temperature. They are also correlated to some degree with a short-day period.

**Determination of the Purity of the Virus:** While the above work was in progress a question arose as to whether the tobacco mosaic virus being used was contaminated with cucumber mosaic virus; Mogendorff (30) having reported that "typical fern-leaf symptoms could not be produced with the ordinary tobacco- or tomato-mosaic virus (Tobacco virus No. 1) under any of the environmental conditions to which the infected host was submitted." As heating at 80°C. for 10 min. inactivates the cucumber mosaic virus, a sample of the tobacco mosaic virus being used was heated to 80°C. for 10 min. and then inoculated into 19 plants that were in the cotyledon stage. Seven of these plants produced typical filiform-leaf symptoms. As aging inactivates the cucumber mosaic virus, a sample of the virus being used that had been stored for ten days was inoculated into 5 plants that were in the cotyledon stage. One of these plants developed typical filiform-leaf symptoms. This work was done during January, 1931. Samples of this virus, and young plants showing typical filiform-and fern-leaf symptoms, were submitted to H. H. McKinney of the United States Dept. of Agriculture for identification. He reported that the virus was a complex of two or more tobacco mosaic viruses but that no cucumber mosaic virus was present in the complex. In comparing the virus being used with a sample of ordinary tobacco mosaic virus, obtained from H. H. McKinney, on a series of differential hosts the symptoms produced by the two viruses were nearly identical. No symptoms of cucumber mosaic were observed.

**1932 Series of Experiments:** During the months of January, February, March and April a series of experiments were conducted using pure samples of cucumber and ordinary tobacco mosaic virus. These samples were kindly furnished by S. P. Doolittle and H. H. McKinney, respectively, of the United States Dept. of Agriculture. The samples were kept on young plants under insect-proof cages. The plants inoculated were inspected for a sufficient length of time to trace the development of the symptoms. The results are presented in the following table. During the course of these experiments the greenhouse was repeatedly fumigated with nicotine to prevent the spread of mosaic by plant lice; none of the check plants became infected showing that no accidental spread occurred.

TABLE 3. EFFECT ON TYPE OF SYMPTOM DEVELOPMENT OF INOCULATING YOUNG PLANTS AT VARIOUS STAGES OF GROWTH WITH CUCUMBER AND ORDINARY TOBACCO MOSAIC VIRUS DURING THE MONTHS OF JANUARY, FEBRUARY, MARCH AND APRIL, 1932

| Date of Inoc. | Stage of Growth | Virus Used | Number Inoc. | Number Infected | First Symptom | | | Second Symptom | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Filiform-leaf | Cut-leaf | Mottling | Fern-leaf | Cut-leaf | Mottling |
| 1-2-32 | First leaf | Cucumber | 11 | 6 | 0 | 0 | 6 | 0 | 0 | 0 |
| | ½″ long | Tobacco | 12 | 0 | .... | .... | .... | .... | .... | .... |
| 1-13-32 | Cotyledons | Cucumber | 13 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 1″ long | Tobacco | 8 | 7 | 5 | 0 | 2 | 4 | 0 | 1 |
| | First Leaf | Cucumber | 9 | 0 | .... | .... | .... | .... | .... | .... |
| | ¼″ long | Tobacco | 8 | 5 | 5 | 0 | 0 | 5 | 0 | 0 |
| | Third leaf | Cucumber | 6 | 2 | 0 | 0 | 2 | 0 | 0 | 0 |
| | ¼″ long | Tobacco | 8 | 5 | 3 | 2 | 0 | 5 | 0 | 0 |
| 1-19-32 | Third leaf | Cucumber | 18 | 3 | 0 | 0 | 3 | 0 | 0 | 0 |
| | ¼″ long | Tobacco | 10 | 9 | 8 | 0 | 1 | 4 | 0 | 4 |
| | Cotyledons | Cucumber | 5 | 0 | .... | .... | .... | .... | .... | .... |
| | 1″ long | Tobacco | 5 | 4 | 4 | 0 | 0 | 4 | 0 | 0 |
| 2-2-32 | Cotyledons | Cucumber | 19 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| | ½″ long | Tobacco | 20 | 13 | 12 | 0 | 1 | 11 | 0 | 1 |
| | Cotyledons | Cucumber | 25 | 2 | 0 | 0 | 2 | 0 | 0 | 0 |
| | ⅜″ long | Tobacco | 22 | 13 | 12 | 0 | 1 | 10 | 0 | 2 |
| | Fourth leaf | Cucumber | 5 | 0 | .... | .... | .... | .... | .... | .... |
| | 1″ long | Tobacco | 5 | 3 | 0 | 0 | 3 | 0 | 0 | 0 |
| 2-10-32 | First Leaf | Cucumber | 15 | 3 | 0 | 0 | 3 | 0 | 0 | 0 |
| | ½″ long | Tobacco | 15 | 10 | 9 | 1 | 0 | 4 | 0 | 6 |
| | First leaf | Cucumber | 15 | 4 | 0 | 0 | 4 | 0 | 0 | 0 |
| | 1″ long | Tobacco | 15 | 10 | 6 | 0 | 4 | 2 | 0 | 4 |
| 2-28-32 | Fourth leaf | Cucumber | 15 | 7 | 0 | 0 | 7 | 0 | 0 | 0 |
| | ¼″ long | Tobacco | 15 | 13 | 0 | 0 | 13 | 0 | 0 | 0 |
| 3-6-32 | Cotyledons | Cucumber | 24 | 2 | 1* | 0 | 1 | 1* | 0 | 0 |
| | ⅜″ long | Tobacco | 19 | 10 | 0 | 5 | 5 | 3 | 0 | 2 |
| 3-16-32 | Cotyledons | Cucumber | 33 | 4 | 1* | 0 | 3 | 0 | 0 | 1 |
| | ½″ long | Tobacco | 23 | 7 | 6 | 0 | 1 | 2 | 0 | 4 |
| | Second leaf | Cucumber | 21 | 1 | 0 | 1* | 0 | 0 | 0 | 1 |
| | 1″ long | Tobacco | 16 | 11 | 7 | 0 | 4 | 0 | 0 | 7 |
| 4-2-32 | Third leaf | Cucumber | 10 | 0 | .... | .... | .... | .... | .... | .... |
| | ½″ long | Tobacco | 17 | 13 | 0 | 0 | 13 | 0 | 0 | 0 |

* Only cases where plants inoculated with cucumber mosaic virus produced leaf abnormality symptoms.

The results obtained with ordinary tobacco mosaic virus in this experiment were almost identical with those obtained with the tobacco mosaic virus complex in the 1930-31 series. Of the 244 plants inoculated with cucumber mosaic virus 36 became infected, and only 3 of these plants showed leaf-abnormality symptoms. One plant showed fern-leaf symptoms. The mottling produced by the cucumber mosaic was very faint.

## Discussion of Results

The results obtained with the use of tobacco mosaic virus show that when young plants, up to the third leaf stage, are inoculated during the winter months typical filiform- and fern-leaf

symptoms are produced. These results are at variance with those mentioned above obtained by Mogendorff (30), working with Bonny Best variety. It should be borne in mind that the term "fern-leaf" is used by Mogendorff to describe all leaf-abnormality symptoms except those described in this paper as "fern-leaf." The results obtained when the virus was heated and aged show that the leaf-abnormality symptoms obtained were not due to the presence of cucumber mosaic virus. In the 1932 series of experiments typical leaf-abnormality symptoms were produced by ordinary tobacco mosaic virus (tobacco virus No. 1) and these symptoms were identical with those in the 1931 series. A later comparison of symptoms produced in Bonny Best and Marglobe showed leaf abnormalities less pronounced on the former, no fern-leaf appearing.

Mogendorff (30) states that "fern-leaf may occasionally be produced by artificial infection of the tomato with cucumber mosaic virus (cucumber virus No. 1)." The results obtained with the use of cucumber mosaic virus in the 1932 series, only three of the plants inoculated producing leaf-abnormality symptoms, are in agreement with those of Mogendorff.

The results obtained in the 1930 summer experiment indicate that the development of leaf-abnormality symptoms may to some degree be correlated with a short-day period. However, the development of these symptoms appears to be correlated to a greater degree with a period of low light intensity such as occurs during the short winter days. This correlation is shown in the 1931 series. McKinney (28) reports that leaf deformities occur most frequently on tobacco plants which are inoculated when very small, and he is of the opinion that they are accentuated by reduced light. As no controlled apparatus for the determination of light intensity was available the effect of high and low light intensity independent of the day length could not be determined. Mogendorff (30) reports that plants inoculated by aphids with cucumber mosaic virus produced typical filiform symptoms when kept under high-light intensity conditions (2,000 watt illumination) for eight hours a day but did not produce symptoms when kept under low-light intensity conditions (500 watt illumination) for the same length of time. Plants inoculated with tobacco mosaic virus did not produce symptoms under the same conditions. Westerdijk (38) reported that leaf-abnormality symptoms were more pronounced on plants grown in the shade. It is apparent from the above that further work is necessary on the question of the effect of light intensity and length of day on the development of leaf-abnormality symptoms.

The work of Kraybill and Eckerson (23) has added another angle to the question of the production of leaf-abnormality symp-

toms. They have reported that the juice of tomato plants affected with mosaic can be separated by means of filtration into two fractions, one of which (the residue) produces mottling symptoms only and the other (the filtrate) which produces fern-leaf symptoms. In a later paper Kraybill, et al., (24) report that this filtrate can be heated to 126 C. for two and a half hours without reducing its activity. This precludes the possibility of cucumber mosaic virus or tobacco mosaic virus in the inoculum. They were unable to make transfers from these fern-leaf plants to healthy plants. They believe that the substance that produces these fern-leaf symptoms is non-living and has the nature of heat stable toxins. The term fern-leaf as used by these workers applies to the symptoms described in this paper as filiform- and cut-leaf.

## HOW INFECTION OCCURS

Any operation which involves the handling or wounding of the plants may be responsible for mosaic infection. In the greenhouse cultural operations are probably responsible for practically all of the mosaic infection. In the field plant lice infect the plants with mosaic. After feeding on a mosaic plant a plant louse becomes a carrier of the virus and when it feeds on a healthy plant it may transmit the disease. Such cultural operations in the field as cultivation, hoeing and picking cause bruising of the plants and are responsible for a great deal of the mosaic infection.

## STAGE WHEN MOSAIC INFECTION MAY OCCUR

In a series of inoculation experiments involving thousands of plants and covering three years' time tomato plants were successfully inoculated with mosaic at all stages of growth—from plants one day above ground to plants having mature fruit.

Although it has been definitely established by Allard (2) and Gardner and Kendrick (15) that mosaic is not seed borne it was of interest to determine if seeds could be successfully inoculated with mosaic. One hundred and fifty seeds of the Marglobe variety and fifty seeds of the Maryland Slicing* variety were inoculated thru the seed coat at the cotyledon end with a No. 00 insect pin that had been dipped in a fresh virus extract just before each seed was inoculated. The seeds were then placed between layers of moist filter paper in a moist chamber fitted with a glass cover. The seeds that germinated were then planted in a flat in the greenhouse. Forty-one plants grew but none of these showed mosaic symptoms five weeks after inoculation.

* A selection made by T. H. White, of this Experiment Station, from one of his crosses.

As previous work had shown that it was possible to successfully inoculate plants in the cotyledon stage, it was next determined if plants in the colorless hypocotyl stage could be successfully inoculated. Tomato seeds were germinated as described above. Inoculations were made when the hypocotyls were one-fourth inch, one-half inch and one inch long; 51 being inoculated when they were one-fourth inch long, 158 when they were one-half inch long and 70 when they were one inch long. Inoculations were made by means of two No. 00 insect pins fastened between two pot labels and spaced three millimeters apart. Before each inoculation was made the pins were dipped in a fresh tomato mosaic virus extract. After inoculation the plants were planted in flats in the greenhouse. The plants were inspected daily for four weeks after being planted but no symptoms of mosaic appeared. This work was done during the winter months.

In another experiment 33 plants were inoculated when the hypocotyls were one-fourth inch long and 30 when the hypocotyls were one-half inch long. After inoculation the plants were transferred to a water germinator in the greenhouse. Tap water was kept flowing continuously thru this germinator. After the plants had been on the germinator for ten days they were transplanted to flats. They were examined for five weeks after being transplanted. One case of mosaic infection was reported on the twenty-fourth day after inoculation. This work was done during February and March.

As the results of the above experiments indicate that plants in the hypocotyl stage cannot be successfully inoculated with mosaic, experiments were carried out to determine what effect exposure of the hypocotyls to light before inoculation would have on infection. In one experiment the plants were left in the germinator until the cotyledons were almost free from the seed coat. They were then exposed to the light for a day before being inoculated. Forty plants were inoculated in the colorless region of the hypocotyls. The inoculated plants were then planted in flats in the greenhouse and they were examined daily for a sufficient length of time for the mosaic symptoms to develop. No mosaic infection occurred. This work was done during March.

In a second experiment the plants were left in the germinator until the cotyledons had developed. They were then exposed to the light for a day, after which sixty were inoculated in the portion of the hypocotyl just below the partly emerged cotyledons and exposed to the light for another day. The plants were then planted in flats in the greenhouse and they were inspected for four weeks. No mosaic infection occurred. This work was done during December and January.

**Discussion of Results:** The results obtained in these experiments indicate that seeds and hypocotyls cannot be successfully inoculated with mosaic. These negative results fit in well with the fact that the mosaic is not seed borne. As the work of Sorokin (34, 35) and Eckerson (14) indicates that mosaic is a disease of the chloroplasts a probable explanation for the negative results obtained in these experiments is that as the chloroplasts may not have developed the virus was unable to act.

Once plants are above ground and contain chlorophyll they can be successfully inoculated with mosaic.

## SPREAD OF MOSAIC DURING TRANSPLANTING

It has been known for a relatively long while that the mosaic disease of tobacco is transmitted in the transplanting process. Clinton (9) in 1914 showed that juice on the hands from mosaic tobacco plants is certain to spread the disease to a very large percentage of the healthy plants handled, and he states that infected plants in the seed bed are probably primarily responsible for most of the mosaic in the field. This work was confirmed by Chapman (6) in 1917. However, no reports substantiated by experimental evidence have been found in the literature relative to the spread of tomato mosaic in transplanting. In their bulletin on tomato mosaic Gardner and Kendrick (15) state "there was convincing evidence in many of the tomato fields examined . . . that mosaic was introduced into the field on the transplants."

Observations in Maryland fields for many years indicate the abundant spreading of mosaic during transplanting. Examinations of fields two to three weeks after transplanting have shown 25 to 50 per cent of diseased plants. More exact data on this point are given under "control of mosaic" on a following page.

## SPREAD OF MOSAIC DURING CULTURAL OPERATIONS

The fact that the mosaic disease of tobacco is spread by cultural operations is well established. By first touching a mosaic tobacco plant and then touching a healthy plant Hunger (20) was able to transmit the disease and he concluded that the spread of mosaic in the field is due to the negligence of the laborers. Selby (33) confirmed Hunger's experiments. In numerous experiments Chapman (6) demonstrated that tobacco mosaic is spread by budding and topping. He also states that mosaic is spread by tools in cultivation but that this spread is very slight. There are numerous observations in the literature relative to the spread of tomato mosaic by such cultural operations as pruning and cultivation, it usually being stated that mosaic may be readily spread by any process which involves handling and wounding of

the plants. Frequent inspections of several tomato fields in 1927-28, made chiefly by A. J. Moyer of this Experiment Station, showed much more spread of mosaic in the direction of cultivation than across the field.

Three field and four greenhouse experiments were carried out to determine the correlation of the spread of mosaic with cultural operations. Records of the cultural operations were kept and the plants were inspected at frequent intervals so that if any spread occurred it could be traced to its source.

**Spread of Mosaic in the Field, 1929:** The field was planted on June 1 with plants of the Marglobe variety, the plants being planted four feet apart in rows four feet apart. The field consisted of fifty rows of fifty plants each. Records of the spread of mosaic were taken on only ten rows at the south side of the field and on ten rows in the center of the field. From July 6 to August 9, inclusive, these rows were inspected thirteen times. The field was cultivated with a horse cultivator on the following dates: June 8, 23, July 10, 23 and August 8. No precautions were taken to avoid bruising the plants during cultivation. Between July 11 and July 15 the mosaic plants present in the field were rogued out. The data and results are presented in Table 4.

TABLE 4. CORRELATION OF THE SPREAD OF MOSAIC WITH CULTURAL OPERATIONS IN THE FIELD, 1929

| Date of Inspection | Number of New Cases of Mosaic Reported | Dates of Cultivation |
|---|---|---|
| July 6 | 2 | |
| " 11 | 3 | |
| " 15 | 6 | |
| " 17 | 2 | |
| " 19 | 3 | |
| " 23 | 8 | |
| " 25 | 9 | July 10 |
| " 27 | 4 | |
| " 29 | 2 | |
| " 31 | 1 | |
| Aug. 5 | 23 | July 23 |
| " 7 | 11 | |
| " 9 | 26 | |

The increase in mosaic July 23-25 is about two weeks after the cultivation on July 10, and the outbreak Aug. 5-9 is associated in a similar way with the July 23 cultivation.

**Spread of Mosaic in the Field, 1930:** The work reported in this experiment was done in a field of tomatoes that were being used to determine the influence of the time of mosaic infection on yield. For a description of the arrangement of the plants and plots refer to Page 467. The field was planted on June 21 with

plants of the Marglobe and Greater Baltimore varieties. All cultural operations in the course of this experiment were performed by the authors. The field was cultivated with a hand cultivator on June 26, July 2 and July 14, care being taken not to let the cultivator come in contact with the plants. From July 14 on the field was hoed once every two weeks until the end of the experiment. The first inspection was made on July 3 and the last inspection on September 19. After the middle of July the detection of mosaic symptoms was very difficult due to the wrinkling, curling and hardening of the leaves caused by extreme drought conditions.

The data are presented in Table 5. In this table it will be noticed that the number of plants under the heading of "No. of plants that on date of inspection should be uninfected" constantly decreases. This is due to the fact that some of the uninoculated plants were used for making inoculations, others were killed by the drought and others were so badly affected by the drought that they had to be discarded. Also, the plants reported with mosaic at the previous inspections are not included in this figure.

TABLE 5. DATA ON THE SPREAD OF MOSAIC IN THE FIELD, 1930

| Date of Inspection | No. of New Cases of Mosaic | No. of Plants That on Date of Insp. Should Be Uninfected | Per Cent of New Cases of Mosaic |
|---|---|---|---|
| July 7 | 20 | 331 | 6.0 |
| " 11 | 21 | 307 | 6.8 |
| " 17 | 17 | 284 | 6.0 |
| " 22 | 11 | 212 | 5.2 |
| " 28 | 6 | 200 | 3.0 |
| Aug. 5 | 5 | 190 | 2.6 |
| " 14 | 6 | 179 | 3.4 |
| " 21 | 8 | 170 | 4.7 |
| " 28 | 4 | 128 | 3.1 |
| Sept. 9 | 2 | 123 | 1.6 |
| " 19 | 33 | 105 | 31.4 |

**Spread of Mosaic in the Field, 1931:** The field was planted on June 4 with plants of the Marglobe variety, the plants being planted four feet apart in rows four feet apart. The field consisted of eight rows of ten plants each. On June 8 the fourth and fifth plants in the second, fourth, sixth and eighth rows were inoculated with mosaic. From June 17 until July 27, inclusive, the field was inspected eight times. On June 20 the inoculated plants showed definite mosaic symptoms. The field was cultivated with a hand cultivator on June 17, June 28 and July 15. Care was taken during the first cultivation to avoid bruising the plants, but during the second and third cultivations the plants were purposely bruised. The data are presented in Table 6.

TABLE 6. CORRELATION OF THE SPREAD OF MOSAIC WITH CULTURAL OPERATIONS IN THE FIELD, 1931

| Date of Inspection | Number of New Cases of Mosaic Reported | Date of Cultivation |
|---|---|---|
| June 17 | 0 | |
| " 20 | 0 | |
| " 24 | 0 | |
| July 1 | 0 | June 17 |
| " 8 | 3 | |
| " 15 | 2 | |
| " 23 | 20 | June 28 |
| " 27 | 40 | July 15 |
| Aug. 5 | 5 | |

## Spread of Mosaic in the Greenhouse

This work was done on tomatoes that were in experimental work on testing the yield of different varieties. The plants were grown on a bed and a bench that were each four feet wide. The plants were spaced a foot apart on each side of the bed and bench except in the last experiment when they were spaced eighteen inched apart. Before the plants were planted they were inspected for mosaic. Inspections were made at approximately three day intervals until the end of the experiments. Records of the cultural operations were kept.

A source of mosaic was always present in this greenhouse as another bench was being used for other experimental work on tomato mosaic.

**Fall Experiment, 1929:** On October 14 plants of the Marglobe and Sterling Castle varieties were transplanted to the bed, 44 plants of the Marglobe variety being planted on one side and 44 plants of the Sterling Castle variety on the other side. No mosaic was found in these plants before transplanting. Only the plants of the Marglobe variety were inspected during the course of the experiment. The first case of mosaic was reported on November 8. The cultural operations were as follows: On October 29 the plants were pruned; on November 4 the plants were tied up, and on November 15 the plants were again pruned and tied up. No precautions were taken during the cultural operations to prevent the spread of mosaic. The data are presented in Table 7.

TABLE 7. CORRELATION OF THE SPREAD OF MOSAIC WITH CULTURAL OPERATIONS IN THE GREENHOUSE, FALL EXPERIMENT, 1929

| Date of Inspection | Number of New Cases of Mosaic Reported | Date of Cultural Operations |
|---|---|---|
| Nov. 8 | 1 | |
| " 11 | 2 | |
| " 12 | 6 | Oct. 29 |
| " 15 | 2 | |
| " 18 | 9 | Nov. 4 |
| " 20 | 1 | |
| " 24 | 5 | Nov. 15 |
| " 29 | 3 | |
| Dec. 4* | 3 | |

* On this date 32 of the 44 plants had mosaic.

**Winter Experiment, 1930:** On February 27 plants of the Marglobe and Sterling Castle varieties were transplanted to the bed. The number of plants used and the arrangement was the same as in the preceding experiment. No mosaic was found in these plants before they were transplanted. The cultural operations were as follows: On March 9 the plants were tied up, on March 23 the plants were pruned and tied up, and on April 16 the plants were also pruned and tied up. No precautions were taken to prevent the spread of mosaic during the cultural operations. The data are presented in Table 8.

TABLE 8. CORRELATION OF THE SPREAD OF MOSAIC WITH CULTURAL OPERATIONS IN THE GREENHOUSE, WINTER EXPERIMENT, 1930

| Date of Inspection | Number of New Cases of Mosaic Reported | Date of Cultural Operation |
|---|---|---|
| March 11 | 0 | |
| " 14 | 1 | |
| " 17 | 1 | |
| " 21 | 8 | March 9 |
| " 24 | 5 | |
| " 27 | 0 | |
| April 1 | 0 | |
| " 4 | 1 | |
| " 6 | 21 | March 23 |
| " 7 | 2 | |
| " 12 | 8 | |
| " 14 | 1 | |
| " 19 | 3 | |
| " 30 | 18 | April 16 |

On April 30th 69, or 78.41 per cent, of the 88 plants had mosaic. Note the great increase in mosaic about two weeks after each cultural operation.

**Fall Experiment, 1930:** On September 12 plants of the Marglobe and Sterling Castle varieties were transplanted to the bed and bench, 44 plants of each variety being planted to both the bed and bench. The arrangement of the plants was the same as in the preceding experiments. The first inspection was made the day after transplanting and one of the Sterling Castle plants in the bench was found to be infected with mosaic. It was rogued out and a replant made. The cultural operations were as follows: On October 3 the plants were tied up, on October 6 the plants were pruned, on October 17 the plants were tied up and pruned, and on October 29 the plants were pruned.

Although the plants were inspected until the fifty-sixth day after transplanting no mosaic was found.

**Winter Experiment, 1931:** The plants used in this experiment were two selections from the Marglobe variety. They will be referred to as Marglobe A and B. Before the plants were transplanted on February 27 they were inspected for mosaic. Thirty-five, or 16.75 per cent, of the 209 plants inspected were found to be infected with mosaic. These mosaic plants were discarded. The plants were transplanted to both the bed and bench, 31 of the Marglobe A and 30 of the Marglobe B being transplanted to both the bed and bench. The plants were spaced eighteen inches apart but the arrangement was the same as in the previous experiments. The cultural operations were as follows: On March 10 the plants in the bed were tied up, on March 18 all the plants were pruned, on March 20 the plants in the bench were tied up, on March 26 all the plants were tied up, and on April 6 all the plants were tied up. No precautions were taken during these cultural operations against the spread of mosaic except on March 26 when the plants were tied up. In tying up the plants on this date the healthy plants were tied before the mosaic plants. The data are presented in the following table.

TABLE 9. CORRELATION OF THE SPREAD OF MOSAIC WITH CULTURAL OPERATIONS IN THE GREENHOUSE, WINTER EXPERIMENT, 1931

| Date of Inspection | Number of New Cases of Mosaic Reported | Date of Cultural Operations |
|---|---|---|
| March 2 | 1 | |
| " 5 | 3 | |
| " 8 | 6 | |
| " 11 | 1 | |
| " 14 | 2 | |
| " 17 | 2 | |
| " 20 | 1 | |
| " 23 | 3 | March 10 |
| " 26 | 5 | March 18 |
| " 29 | 5 | |
| April 1 | 7 | March 20 |
| " 4 | 2 | |
| " 7 | 1 | March 26 |
| " 10 | 2 | |
| " 13 | 9 | |
| " 16 | 8 | April 6 |
| " 19 | 12 | |

On April 19th 70, or 57.38 per cent, of the 122 plants had mosaic.

## Discussion of Results

In all of the experiments where no precautions were taken against the spread of mosaic during the cultural operations a pronounced increase in the number of plants reported mosaic occurred during a period of eight to seventeen days after each cultural operation as shown in the preceding tables. When precautions were taken during the cultural operations to prevent the spread of mosaic, increase in the number of plants reported mosaic rarely occurred. In the 1929 and 1931 field experiments the spread of mosaic up and down the rows was greater than across the rows, showing that it was being spread in the direction of cultivation. The slow spread of mosaic in the 1930 field experiment was partly due to drought conditions. The pronounced increase in mosaic reported on the last date of inspection was due to the fact that the plants were in a fairly succulent state, having had some good rains the latter part of August, and were thus easily bruised while inspections and pickings were being made ten to fifteen days before this date of inspection.

Although there was a continual slow spread of mosaic throughout each season attributable to aphids or other natural agencies, the outbreaks that follow cultivations show that the former agencies were a minor factor in the spread.

In the greenhouse experiments insects were not a factor in the spread of mosaic as the greenhouse was fumigated at frequent intervals. As the plants in the greenhouse were grown so close together one would expect that the healthy plants that were in contact with a mosaic plant would soon become infected. The results obtained, however, show that little, if any, spread of mosaic occurred in this manner.

In the 1930 fall experiment in the greenhouse where a mosaic plant was found the day after transplanting it would be expected that a spread of mosaic during the transplanting process would have occurred; however, such was not the case. No other plants were reported with mosaic as late as the fifty-sixth day after transplanting. As this plant was rogued out no spread occurred during the cultural operations for a source of mosaic was not present in the plants handled.

## INFLUENCE OF MOSAIC INFECTION ON TOMATO YIELDS

The literature relating to the mosaic disease of the tomato is replete with statements of observations on the reduction in yield being associated with time of infection. Gardner and Kendrick (15) state: "It is a matter of common observation that many plants infected early in the season may show very extreme effects of mosaic and bear no marketable fruit whatever. Others may bear a greatly reduced yield, while, in the case of plants infected late in the season, the effect on the yield is not very noticeable." In a later paper (17) these investigators again call attention to the fact that early infections cause the greatest loss. McKay (27) observed in Oregon, under both field and greenhouse conditions, that yields from mosaic-infected plants varied greatly, some yielding about a third of an average crop while others produced apparently an average yield. However, the literature reveals very little exact data upon the correlation of these losses with the time of infection. Norton (32) showed by measurements in the greenhouse that, although 33 per cent more fruit set on the plants longest remaining healthy, they produced very little more weight of fruit than plants infected earlier. McCubbin (26), under field conditions in Ontario in 1915, showed that 59 healthy plants gave 36.8 per cent more fruit and 40.5 per cent more weight of fruit than 59 mosaic plants. However, he does not state when his mosaic plants were infected. Unpublished observations made by J. B. S. Norton and R. A. Jehle during several years in Maryland tomato fields showed lower yields from the earlier infected plants. The investigations reported below were undertaken with the object of obtaining more exact data on the effect of early and late infections of the common type

of tomato mosaic on the yield of tomatoes under Maryland conditions. Part of the work reported below has already been published.*

## Methods and Results

**1927 Field Experiment:** On July 1 a careful examination in a plot of Greater Baltimore tomato plants 6 to 8 inches tall, planted June 10, was made for individuals showing mosaic symptoms. The location of infected plants was recorded on a chart. Thereafter, 6 examinations at intervals of 1 week were made and, from the data obtained, 10 plants were selected from each weekly survey for yield studies. Harvests of ripe fruit were made at intervals of 1 week from August 22 to September 22, inclusive. Total yields for each of 6 series, based on the time of appearance of mosaic symptoms, were obtained. The average yield per plant for each series is presented in Table 10. Under existing field conditions it was not possible to find by the first harvest 10 mosaic-free plants. Therefore, the yield of those plants which showed infection on August 12 was used as the basis for loss calculations. The 1927 growing season was approximately an average one.

TABLE 10. SUMMARY OF YIELD RECORDS OF INFECTED TOMATO PLANTS COMPRISING THE 1927 EXPERIMENT

| Time of Appearance of Symptoms | Number of Plants | Average Yield Per Plant in Grams | Percentage Loss Due to Mosaic |
|---|---|---|---|
| July 8 | 4 | 1,993 | 56.9 |
| " 15 | 10 | 2,854 | 38.2 |
| " 22 | 10 | 3,488 | 24.5 |
| " 29 | 10 | 4,122 | 10.8 |
| Aug. 5 | 10 | 4,532 | 1.9 |
| " 12 | 10 | 4,621 | ..... |

**1930 Field Experiment:** Two series of 3 plots, each, were laid off side by side on a comparatively level piece of sandy loam soil. In each series 2 plots were planted to the Marglobe variety and 1 plot to the variety Greater Baltimore. Half of the plots of each variety was used for inoculations and the other half for controls. Similar fertilizer treatments and cultural practices were employed throughout.

Plants were obtained from beds apparently free from mosaic and were set on June 21 four feet apart in rows 4 feet apart. These plants were about a week older than the usual age for transplanting. The late planting was due to the fact that the soil was not previously available. During the transplanting pro-

* Heuberger, J. W., and A. J. Moyer. Influence of Mosaic Infection on Tomato Yields. Phytopath. 21: 745-749. 1931.

cess the hands of the workers were frequently washed with soap and water, and only strong, vigorous, healthy plants were set out.

All experimental inoculations were made by a slight modification of the needle-prick method devised by Holmes (18). Four inoculations were made during the growing season: the first, at transplanting time; the second, when the first flower cluster had formed; the third, when the first fruits set were ½ to 1 inch in diameter; and the fourth, when the first fruits were ripe.

All precautions were taken to prevent the spread of mosaic by mechanical means. The field was inspected at weekly intervals for the appearance of cases of accidental infection and for the presence of aphids. Aphids were scarce throughout the season except for a small number being present just after the plants were set out. The accidental spread of mosaic was unusually slow and, at the end of the growing season, 51 plants in the control plots were still healthy. These accidental cases of infection are not included in the data.

Harvesting began on September 3 and continued until October 3. The yield records are summarized in Table 11.

Drought conditions prevailed throughout the season and, for the months of June, July, August, and September, a deficiency of 11.01 inches of rainfall occurred, there being during this period only 29.47 per cent of the average rainfall.

TABLE 11. SUMMARY OF YIELD RECORDS OF HEALTHY AND INOCULATED TOMATO PLANTS COMPRISING THE 1930 EXPERIMENT

| Date of Inoculation | Number of Plants Used | Average Number of Fruits Set Per Plant | Average Yield Per Plant in Grams | Percentage Loss Due to Mosaic |
|---|---|---|---|---|
| First (6-26-30)..... | 39 | 21 | 685 | 54.4 |
| Second (7-11-30)..... | 39 | 24 | 836 | 44.4 |
| Third (8-14-30)..... | 27 | 32 | 1,122 | 25.3 |
| Fourth (9- 3-30)..... | 13 | 32 | 1,335 | 11.2 |
| Control Plants..... | 51 | 36 | 1,503 | ..... |

**1931 Field Experiment:** Two plots were laid off side by side on a comparatively level piece of sandy loam soil. Plants of the Marglobe variety were obtained from open beds apparently free from mosaic and were planted on June 4 four feet apart in rows four feet apart. One plot was used for inoculations and the other plot was used for controls. The transplanting procedure, the method of making inoculations, and the stage of growth of the plants at which inoculations were made was the same as in the preceding experiment. Precautions were taken to prevent the spread of mosaic by mechanical means, and the field was inspected at weekly intervals for the appearance of accidental cases of mosaic.

Harvesting began on August 5 and continued until September 28. The yield records are summarized in Table 12.

TABLE 12. SUMMARY OF YIELD RECORDS OF HEALTHY AND INOCULATED PLANTS COMPRISING THE 1931 EXPERIMENT

| Date of Inoculation | Number of Plants Used | Average Number of Fruits Set Per Plant | Average Yield Per Plant in Grams | Percentage Loss Due to Mosaic |
|---|---|---|---|---|
| First (6- 8-31)..... | 40 | 10 | 692 | 53.9 |
| Second (6-29-31)..... | 40 | 16 | 1,096 | 26.9 |
| Third (7-14-31)..... | 34 | 15 | 1,125 | 25.0 |
| Fourth (8- 3-31)..... | 29 | 17 | 1,241 | 17.3 |
| Control Plants ..... | 60 | 19 | 1,500 | ..... |

**1931 Greenhouse Experiment:** Yield records were taken on the plants comprising the 1931 winter experiment on the spread of mosaic. Harvesting of ripe fruit began on May 15 and continued until June 22. A record of the yield of each individual plant was kept. As no record of the spread of mosaic was kept after the fifty-first day from transplanting the yield of the plants still healthy at that date was used as the basis for loss calculations. Harvesting did not begin until the seventy-sixth day after transplanting. The yield records are summarized in the following table.

TABLE 13. SUMMARY OF YIELD RECORDS OF HEALTHY AND MOSAIC PLANTS COMPRISING THE 1931 GREENHOUSE EXPERIMENT

| Plants | Location | Condition | No. of Plants Used | Ave. No. of Fruits Set Per Plant | Ave. Yield Per Plant in Grams | Percentage Loss Due to Mosaic |
|---|---|---|---|---|---|---|
| Marglobe A | Bench | Healthy..... | 9 | 21 | 2,914 | 10.9 |
| | | Mosaic..... | 22 | 19 | 2,597 | |
| | Bed | Healthy..... | 12 | 12 | 1,327 | 23.9 |
| | | Mosaic..... | 19 | 12 | 1,010 | |
| Marglobe B | Bench | Healthy..... | 18 | 16 | 2,048 | ..... |
| | | Mosaic..... | 12 | 18 | 2,366 | |
| | Bed | Healthy..... | 13 | 16 | 1,731 | 15.0 |
| | | Mosaic..... | 17 | 13 | 1,471 | |

The average yield of all the healthy plants was 2,020 grams, while that of all the mosaic plants was 1,875 grams, a reduction of 7.13 per cent. In one case the infected plants outyielded the healthy plants.

## Discussion of Results

**Field Experiments:** Although these experiments were conducted under different climatic conditions, practically identical

results were obtained. In 1927 the greatest loss in yield occurred with plants showing symptoms by July 8, while in 1930 and 1931 the plants inoculated a few days after transplanting produced a decidedly lower yield than those inoculated later. In all three experiments later infections produced similar results—the later the time of infection the less the reduction in yield. The results obtained show that the decrease in yield varies in direct relation to the earliness of infection. McMurtrey (29) and Valleau and Johnson (36), working with tobacco, obtained the same relation.

Although the results of the later infections show the same relation, they differ quantitatively in the 3 years, and these differences seem to bear a definite relation to cultural practices and climatic conditions. The plants used in 1927 and 1931 were transplanted about 2 weeks earlier and were somewhat younger and smaller than those used in 1930. The growing seasons of 1927 and 1931 were approximately average, while during the growing season of 1930 a severe drought was in progress. Thus, in 1927 and 1931 the plants grew faster and matured fruit earlier than in 1930. These differences indicate that late infection of plants of retarded growth may cause more damage than late infection of plants of average growth. For example, the figures in Table 10 show a 24.5 per cent loss when symptoms appeared on July 22, infection approximately 12 days earlier, and those in Table 12 show that infection on July 14 resulted in 25.0 per cent loss, while the figures in Table 11 show a 44.4 per cent loss when infection occurred on July 11. The figures in Tables 11 and 12 for the average number of fruits set per plant show that early infections resulted in considerably less fruit being set than on healthy plants. The average weight of the fruits in the first infections is 32.6 grams and 69.2 grams, in the healthy plants 41.8 and 79.0 grams.

**Greenhouse Experiment:** The results obtained show a pronounced difference between the yield of the plants on the bench and the plants in the bed. Unpublished results of tests covering several years' time, conducted by T. H. White of this Station on the same bed and bench used in this experiment, show decidedly higher yields from plants grown on the bench. The plants in the bed are in an apparently unfavorable condition for best growth and seem to be more severely affected by the mosaic than the plants on the bench which are in an apparently favorable condition for best growth.

## EFFECT OF MOSAIC ON THE CANNING QUALITY OF TOMATOES

Although no record of any work on the effect of mosaic on the canning quality of tomatoes has been found in the literature,

there are several references to work that would indicate that the quality of the fruit might be affected by mosaic. Allard (2) has shown that the virus is present in green and ripe fruits. In a chemical analysis of healthy and mosaic tomato plants Brewer et al. (5) found that the mosaic plants were characterized by a reduction in their total carbohydrate content, the reduction taking place mainly in the polysaccharides, and by no marked decrease in their nitrogen content. In this work entire tomato plants, including green fruits, were used. They also found that in all cases the mosaic plants were characterized by a reduction in total fresh weight and in percentage content of dry matter.

In 1929 a preliminary test was made on the effect of mosaic on the quality of the canned fruit. Six cans each of healthy and mosaic fruit were prepared and then scored by an expert scorer, using the score sheet for canned tomatoes, tentative draft of January, 1928, of the National Canners' Association. The results are presented in Table 14.

TABLE 14. EFFECT OF MOSAIC ON THE CANNING QUALITY OF TOMATOES

| Test | Healthy (Ave. of 6 Cans) | Mosaic (Ave. of 6 Cans) |
|---|---|---|
| Solidity | 28.0 | 27.6 |
| Color | 18.1 | 17.5 |
| Freedom from skins, etc. | 15.0 | 15.0 |
| Flavor | 9.6 | 10.1 |
| Percentage of whole tomatoes | 8.0 | 7.8 |
| Total score | 78.7 | 78.0 |
| Percent drained weight | 72.39 | 71.7 |
| Specific gravity | 1.1913 | 1.1891 |

As the differences in the scores of the healthy and mosaic cans were so negligible no further experiments were carried out.

## EFFECT OF MOSIAC ON THE PLANT

In addition to producing mottling and leaf distortion on infected plants mosaic causes a reduction in the size of the plant, this reduction being especially noticeable on early infected plants. Figures will be presented later showing the effect of mosaic on the green weight, dry weight and leaf area of the plant. Several investigators have shown that the palisade cells of an infected leaf are reduced to cuboidal cells that resemble the spongy parenchyma cells, and that the leaf is much thinner than a healthy leaf. Eckerson (14) and Sorokin (34, 35) have shown that the chloroplasts are materially affected by the mosaic, and Dunlap (13) has shown that the total chlorophyll content of mosaic tobacco plants is seriously reduced.

All of the above work strongly indicates that mosaic may have a pronounced effect upon the transpiration rate of the plant. Also, field observations covering several years seemed to indicate that mosaic plants wilted more than healthy plants. Accordingly, three different lines of investigation were carried out, namely: the determination of the drying rates of healthy and mosaic leaves, the determination of the transpiration rates of healthy and mosaic leaves, and the determination of the transpiration rates of healthy and mosaic plants.

### Drying Rates of Healthy and Mosaic Leaves

In determining the drying rates of healthy and mosaic leaves equal weights of leaves were taken from corresponding positions on plants of equal age. These were laid out on a laboratory table to dry; the table being so placed that the leaves received equal illumination. During the first day the leaves were weighed at two hour intervals, but thereafter they were weighed once a day at five o'clock until the mosaic leaves had reached a fairly constant weight. The experiment was repeated three times with practically identical results. The results of one test are presented below.

TABLE 15. DRYING RATES OF 20 GRAMS OF HEALTHY AND MOSAIC LEAVES

| Date | Time of Weighing | Weight of Leaves | | Loss in Weight of Leaves | |
|---|---|---|---|---|---|
| | | Healthy | Mosaic | Healthy | Mosaic |
| | | Grams | Grams | Per Cent | Per Cent |
| 4-18-31 | 9:00 a. m. | 20.0 | 20.0 | ..... | ..... |
| " | 11:00 " | 17.5 | 16.8 | 12.5 | 16.0 |
| " | 1:00 p. m. | 16.8 | 15.7 | 16.0 | 21.5 |
| " | 3:00 " | 16.1 | 14.6 | 19.5 | 27.0 |
| " | 5:00 " | 15.3 | 13.6 | 23.5 | 32.0 |
| 4-19-31 | " " | 11.0 | 8.4 | 45.0 | 58.0 |
| 4-20-31 | " " | 8.7 | 5.8 | 56.5 | 71.0 |
| 4-21-31 | " " | 7.1 | 4.5 | 64.5 | 77.5 |
| 4-23-31 | " " | 5.5 | 3.7 | 72.5 | 81.5 |
| 4-24-31 | " " | 4.7 | 3.5 | 76.5 | 82.5 |
| 4-25-31 | " " | 3.9 | 3.3 | 80.5 | 83.5 |
| 4-26-31 | " " | 3.7 | 3.3 | 81.5 | 83.5 |

The results presented in the above table show that the mosaic leaves lost their water at a faster rate and became dry sooner than the healthy leaves.

### Transpiration Rates of Healthy and Mosaic Leaves

The transpiration rates were determined by the method of standardized hygrometric paper (25). During the afternoon of

December 31, 1930, several readings were taken on both the upper and lower surfaces of a healthy and a mosaic leaf on plants growing in nutrient solution; the readings being taken while the sun was shining between the hours of one and three o'clock. The leaves used were in approximately the same stage of development and were in corresponding positions on plants of equal age. The data are presented in the following table:

TABLE 16. MEAN READINGS OF THE TRANSPIRATION RATES OF A FREE WATER SURFACE AND THE UPPER AND LOWER SURFACE OF A HEALTHY AND A MOSAIC LEAF, AND THE INDEX OF THE RELATIVE TRANSPIRING POWER OF THE UPPER AND LOWER SURFACE OF A HEALTHY AND A MOSAIC LEAF.

| Reading | Standard Water Surface | Leaf Surface | | | |
|---|---|---|---|---|---|
| | | Healthy | | Mosaic | |
| | | Upper | Lower | Upper | Lower |
| Time required for cobalt - chloride paper to change color | 68 sec. | 697 sec. | 285 sec. | 172 sec. | 112 sec. |
| Index of the relative transpiring power* | 1 | 0.098 | 0.239 | 0.395 | 0.607 |

* Time required to effect the color change in the cobalt-chloride paper over the standard water surface divided by the time required to effect the color change on the leaf surface.

The results obtained show that the upper surface of a mosaic leaf was transpiring four times as fast as the upper surface of a healthy leaf, while the lower surface was transpiring two and a half times as fast.

### Transpiration Rates of Healthy and Mosaic Plants

In determining the transpiration rates of healthy and mosaic plants the general procedure was as follows: Seed of the Marglobe variety was germinated in a moist chamber and when the hypocotyls were approximately an inch long the seeds were transferred to a water germinator. When the first leaf was about an inch long the seedlings were transferred to Mason jars containing a complete nutrient solution and were placed in the greenhouse. The complete nutrient solution used was that of Johnston (22). When the plants had reached the desired height readings were begun. At each reading the jars were weighed separately and the loss in weight from the previous reading was taken as the amount of transpiration. The plants were inoculated at the desired time; an equal number of plants being left uninoculated. At the end of the experiments

the green weight of the tops and roots was found, and then the tops and roots were placed in a drying oven at a temperature of 100°C. for 30 hours, after which the dry weight was found. The stage of growth at which the plants were inoculated, the time at which readings were begun, and the length of time the readings were taken varied in the several experiments.

In one experiment the leaf area of the plants was found. This was done by obtaining a print of the leaflets on photographic paper and then measuring their area with a planimeter.

**Experiment I:** When the fifth leaf of the plants was approximately an inch long, five plants were inoculated. Five uninoculated plants were kept as controls. When the plants had reached a height of fifteen inches the inoculated plants were showing severe symptoms of mosaic, so readings were begun, readings being taken at two hour intervals from 9:00 a. m. to 9:00 p. m., inclusive, on January 3, and from 9:00 a. m. to 5:00 p. m., inclusive, on January 5, 1930. The green and dry weights of the tops and roots were then found. The data are presented below.

TABLE 17. AVERAGE GREEN WEIGHT AND DRY WEIGHT OF THE 5 HEALTHY AND 5 MOSAIC PLANTS

| Reading | Tops | | | Roots | | |
|---|---|---|---|---|---|---|
| | Healthy | Mosaic | Loss Due to Mosaic | Healthy | Mosaic | Loss Due to Mosaic |
| | Grams | Grams | Per Cent | Grams | Grams | Per Cent |
| Green wt.... | 34.44 | 27.30 | 20.7 | 11.24 | 6.46 | 42.5 |
| Dry wt..... | 3.136 | 2.324 | 25.9 | 0.697 | 0.424 | 39.2 |

TABLE 18. AVERAGE TRANSPIRATION OF 5 HEALTHY AND 5 MOSAIC PLANTS FOR EACH TWO HOUR PERIOD

| Date | Period | Average Transpiration | | Average Transpiration Per Gram Dry Weight | |
|---|---|---|---|---|---|
| | | Healthy | Mosaic | Healthy | Mosaic |
| | | Grams | Grams | Grams | Grams |
| 1-3-30 | 9-11 a. m. | 6.06 | 4.50 | 1.93 | 1.94 |
| " | 11- 1 p. m. | 12.76 | 7.84 | 4.06 | 3.38 |
| " | 1- 3 " | 7.56 | 4.80 | 2.41 | 2.07 |
| " | 3- 5 " | 4.80 | 2.34 | 1.50 | 1.01 |
| " | 5- 7 " | 2.98 | 2.28 | 0.95 | 0.98 |
| " | 7- 9 " | 2.02 | 1.62 | 0.64 | 0.70 |
| 1-5-30 | 9-11 a. m. | 5.24 | 2.78 | 1.67 | 1.20 |
| " | 11- 1 p. m. | 5.80 | 3.70 | 1.85 | 1.70 |
| " | 1- 3 " | 6.68 | 3.92 | 2.13 | 1.69 |
| " | 3- 5 " | 4.50 | 2.50 | 1.43 | 1.08 |

The results of this experiment show that the healthy plants transpire a greater total amount of water than the mosaic plants,

and that they transpire more water per gram dry weight. Between the hours of five and nine o'clock at night there is an equalization of transpiration, which would be expected in the more saturated atmosphere.

**Experiment II:** In this experiment plants were used that had been affected with mosaic for a longer period of time than those used in the previous experiment. The plants were inoculated on February 10, 1931, when the fifth leaf was approximately an inch long. On February 24 the five inoculated plants showed well defined symptoms of mosaic, but readings were not begun until March 15. The 5 mosaic and 5 healthy plants were weighed daily at 5:00 p. m. until March 26. After the last reading the leaf area of the healthy and mosaic plants was determined. Three days were required to make prints of the leaves, but the error thus introduced is not believed to be significant as prints of the leaves of the healthy and mosaic plants were made alternately. As approximately two thousand prints of the leaves were measured with the planimeter the error in the individual planimeter readings would tend to be compensated. After the leaf prints had been made the dry weight of the tops and roots was determined. The data are presented below.

TABLE 19. AVERAGE LEAF AREA, DRY WEIGHT OF TOPS AND DRY WEIGHT OF ROOTS OF 5 HEALTHY AND 5 MOSAIC PLANTS

| Reading | Average of 5 Healthy | Average of 5 Mosaic | Loss Due to Mosaic |
|---|---|---|---|
| Leaf area | 336.77 sq. in. | 223.86 sq. in. | 33.53 |
| Dry wt. of tops | 15.522 grams | 8.535 gms. | 45.01 |
| Dry wt. of roots | 4.357 " | 2.498 " | 42.67 |

TABLE 20. AVERAGE TRANSPIRATION OF 5 HEALTHY AND 5 MOSAIC PLANTS PER DAY PERIOD

| Period | Average Transpiration | | Reduction in Transpiration Due to Mosaic* |
|---|---|---|---|
| | 5 Healthy | 5 Mosaic | |
| March | Grams | Grams | Per Cent |
| 15 - 16 | 93.1 | 42.2 | 54.7 |
| 16 - 17 | 220.7 | 110.2 | 50.1 |
| 17 - 18 | 283.9 | 156.7 | 44.8 |
| 18 - 19 | 98.3 | 55.8 | 43.2 |
| 19 - 20 | 157.9 | 109.7 | 30.5 |
| 20 - 21 | 257.7 | 179.9 | 30.2 |
| 21 - 22 | 76.7 | 55.3 | 27.6 |
| 22 - 23 | 260.4 | 183.9 | 29.4 |
| 23 - 24 | 179.4 | 137.3 | 23.5 |
| 24 - 25 | 219.6 | 173.9 | 20.8 |
| 25 - 26 | 223.0 | 166.2 | 25.5 |

* Difference between transpiration of healthy and mosaic expressed as per cent of the healthy.

The figures in the above table show that the healthy plants are transpiring more water than the mosaic plants. At the start of the experiment they were transpiring over twice as much water as the mosaic plants, but at the end they were transpiring only a quarter more. It should be borne in mind that the mosaic plants were considerably smaller than the healthy plants, as is shown in Table 19. The figures in the last column of Table 20 indicate that as the mosaic plants get older they transpire water at a faster rate per gram dry weight and per square inch of leaf surface. Accordingly, the amount of transpiration per gram dry weight and per square inch of leaf area was determined. The figures are presented in Table 21.

TABLE 21. AMOUNT OF TRANSPIRATION PER GRAM DRY WEIGHT AND PER SQUARE INCH OF LEAF AREA OF THE AVERAGE OF 5 HEALTHY AND 5 MOSAIC PLANTS

| Period | Average Transpiration | | | |
|---|---|---|---|---|
| | Per Gram Dry Weight | | Per Square Inch of Leaf Area | |
| | 5 Healthy | 5 Mosaic | 5 Healthy | 5 Mosaic |
| March | Grams | Grams | Grams | Grams |
| 15 - 16 | 6.00 | 4.94 | 0.276 | 0.189 |
| 16 - 17 | 14.22 | 12.91 | 0.655 | 0.492 |
| 17 - 18 | 18.29 | 18.36* | 0.843 | 0.700 |
| 18 - 19 | 6.33 | 6.54 | 0.292 | 0.249 |
| 19 - 20 | 10.11 | 12.85 | 0.469 | 0.490* |
| 20 - 21 | 16.60 | 21.08 | 0.765 | 0.804 |
| 21 - 22 | 4.94 | 6.50 | 0.228 | 0.248 |
| 22 - 23 | 16.78 | 21.55 | 0.773 | 0.821 |
| 23 - 24 | 11.55 | 16.09 | 0.533 | 0.613 |
| 24 - 25 | 14.14 | 20.37 | 0.652 | 0.777 |
| 25 - 26 | 14.36 | 19.47 | 0.662 | 0.742 |

* Mosaic began to transpire more than healthy.

The figures in the above table bring out an interesting point, namely: that although the healthy plants transpired more water per unit of measure than the mosaic plants at the start of the experiment they transpired much less at the end. This shows that the transpiration rate of the mosaic plants is being accelerated.

The results obtained in Experiment II raised several questions. How soon after inoculation does the mosaic have an effect upon the transpiration rate? Is the first effect to accelerate or retard transpiration? If the first effect is to retard transpiration, as indicated in Experiment II, when does the transpiration become accelerated?

During the spring of 1931 a preliminary experiment was carried out to secure information on these points. The results obtained indicate that the transpiration of the inoculated plants is not affected during the incubation period of the virus, but that as soon as symptoms appear it is materially retarded. This retarding effect appears to be temporary and the transpiration is then accelerated.

The following experiments were carried out to secure additional information on the above questions, and to secure data on the effect of the mosaic virus during its incubation period on the dry weight of the plant.

**Experiment III:** Readings were begun on January 4, 1932, on 20 plants, the weighings being made daily at 8:00 a. m. After eight daily readings on the amount of transpiration of each plant had been made the plants were balanced in four groups of 5 plants each, balancing being done on the basis of the average total transpiration of each group of 5 plants for the 8 readings. By this method it was possible to obtain 2 series of 10 plants each, the 10 plants in each series being divided into 2 groups of 5 plants having practically the same average total transpiration. In Series I the average total transpiration of Group 1 was 692.7 grams, and that of Group 2 was 692.3 grams, and in Series II the average total transpiration of Group 1 was 708.7 grams, and that of Group II was 712.2 grams. The 5 plants in Group 2 of each series were inoculated on January 12. At this time the plants were 21 inches high and had the first flower cluster well formed. When the inoculated plants in Series I showed definite mosaic symptoms they, and the healthy plants, were cut and the green and dry weights found. Daily readings were continued on the plants in Series II until February 16, at which date all the plants in this series were cut and the dry weights found. The data are presented in Table 22 and Graphs 1 and 2.

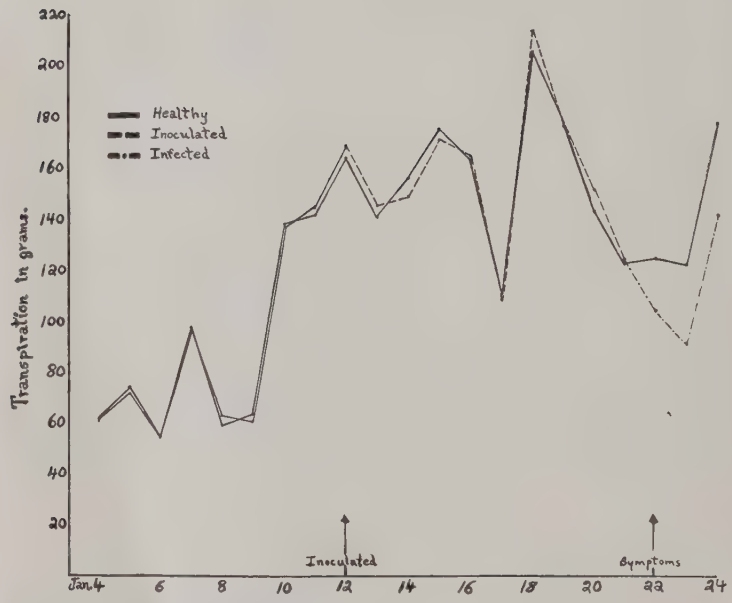
TABLE 22. AVERAGE GREEN AND DRY WEIGHT OF THE HEALTHY AND INOCULATED PLANTS IN EXPERIMENT III

| | Series | Plants | Green Wt. (Grams) | Dry Wt. (Grams) | Loss in Dry Wt. Due to Mosaic |
|---|---|---|---|---|---|
| | | | | | Per Cent |
| Tops | I | Healthy | 96.6 | 8.306 | 0.36 |
| | | Mosaic | 92.3 | 8.276 | |
| | II | Healthy | ..... | 25.003 | 15.50 |
| | | Mosaic | ..... | 21.127 | |
| Roots | I | Healthy | 19.3 | 1.444 | 0.022* |
| | | Mosaic | 18.9 | 1.466 | |
| | II | Healthy | ..... | 5.737 | 20.26 |
| | | Mosaic | ..... | 4.573 | |

* Increase in favor of mosaic.

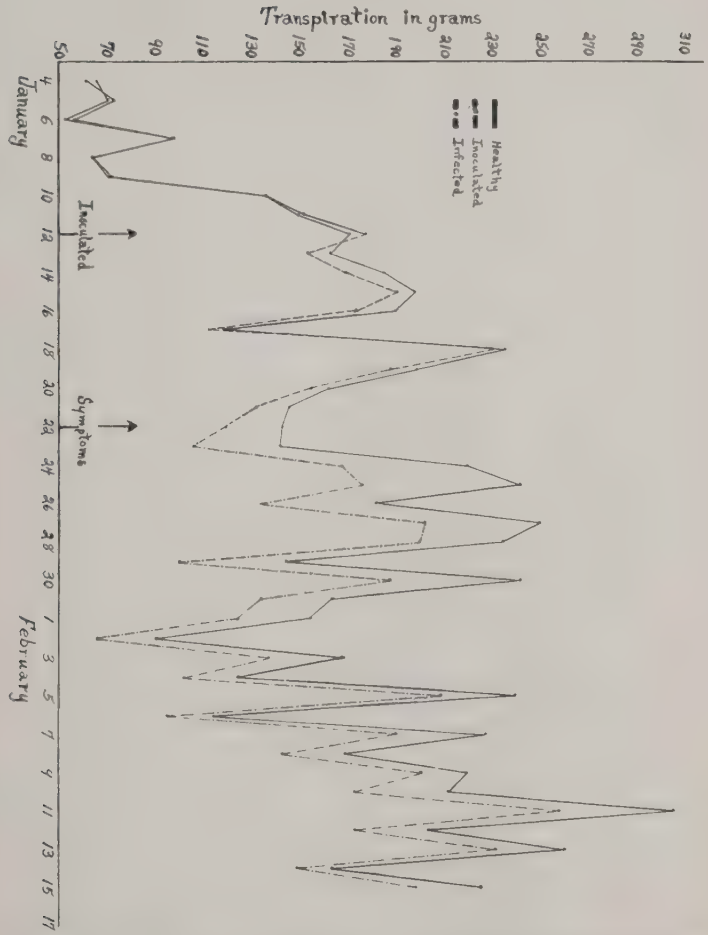
The figures presented in this table indicate that the mosaic virus during its incubation period in the plants has little or no effect on the dry weight of either the tops or the roots.

GRAPH 1




GRAPH 1. AVERAGE TRANSPIRATION OF THE 5 HEALTHY AND 5 INOCULATED PLANTS IN SERIES I OF EXPERIMENT III

GRAPH 2




GRAPH 2. AVERAGE TRANSPIRATION OF THE 5 HEALTHY AND 5 MOSAIC PLANTS IN SERIES II OF EXPERIMENT III

Both of these graphs show that the mosaic virus has no effect on the amount of transpiration during its incubation period in the plant. However, coincident with the appearance of mosaic symptoms there was a pronounced drop in the amount of transpiration of the infected plants. Graph 2 shows that the infected plants transpire considerably less water than the uninfected plants for quite a length of time after symptoms appear, but that gradually they transpire an amount of water approaching that of the uninfected plants, even though at this time they are considerably smaller. This might be accounted for by two factors. First: that the long-infected mosaic leaves are transpiring water at a faster rate. Second: that the number of leaves affected by the mosaic disease constantly increases as the plants continue to grow. What effect the virus has on the transpiration of the leaves formed before infection, which do not show symptoms although they contain the virus, is not known.

Experiment III was repeated with almost identical results. However, the sixth day after inoculation there was a slight rise in the transpiration of the infected plants, and on the eleventh day a slight drop occurred. This experiment was carried out when the days were longer and the temperature higher, and the plants were kept for a longer period of time after symptoms had appeared. At the end of the experiment the mosaic plants were transpiring almost as much water as the healthy plants.

## Discussion of Results

The more rapid loss of water from detached mosaic-infected leaves, and the increased transpiration of mosaic-infected leaves on diseased plants, is in accord with the known effect of the virus on leaf structure. The effect of the virus on the stomata has not been determined.

In the experiments on plants growing in nutrient solution it was to be expected that the healthy plants would transpire a greater total quantity of water than the mosaic plants which, due to slower growth, were becoming relatively smaller. The increase in the amount of transpiration per unit of measure of the infected plants, as shown in Experiments II and III, indicates that the effect of the virus becomes more marked on the transpiration rate the longer the plants are infected. Thus, although a mosaic plant may be only two-thirds as large as a healthy plant, it transpires almost as much water.

The lack of expansion of the young apical leaves, so noticeable in Experiment III as a first mosaic symptom, may possibly account for the pronounced drop in transpiration occurring simultaneously. These leaves expand after a few days and the amount of transpiration of the infected plants begins to increase slowly. (See Graph 2.)

## METHODS OF OVERWINTERING

The question of how the mosaic virus passes thru the winter is one of prime importance, especially from the standpoint of devising control measures against the disease. Many investigators have shown that the mosaic virus can exist for long periods in dead plant material. This may be a means of it passing thru the winter in the field. Early investigators believed that the soil was an important source of infection, but Allard (1) concluded from his results that mosaic infection from the soil was of infrequent occurrence. From the results of their tests with cucurbit mosaic Doolittle and Walker (11) concluded that the virus did not live over winter in the soil. In a later paper Doolittle (12) reports that the virus of tomato mosaic will live in greenhouse soils for at least 70 days and that it will live from 4 to 6 weeks in field soil. Johnson and Ogden (21) carried on extensive experiments on the overwintering of tobacco mosaic virus in the soil and obtained evidence that the virus may overwinter in the soil. They also found that moist and well aerated soils favor the inactivation of the virus as compared with dry, compact or waterlogged soils. However, the question of the overwintering of the mosaic virus in the soil is still a debatable one.

In recent years a great deal of importance has been attached to the overwintering of the mosaic virus in perennial weeds. Crawford (10) and Gardner and Kendrick (16) have definitely proven that the tomato mosaic virus is carried thru the winter in the rootstocks of such perennial weeds as the horse nettle *(Solanum carolinense)*, and various species of ground cherries *(Physalis spp.)*. These infected weeds send up mosaic shoots in the spring and plant lice carry the mosaic from these shoots to the tomato plant. Gardner and Kendrick (17) are of the opinion that these perennial weeds are primarily responsible for infection in the field. These perennial weeds are found in Maryland tobacco and tomato fields, the horse nettle *(Solanum carolinense)* being very common. During the fall of 1930 several ground cherry plants that were infected with mosaic were dug up and planted in the greenhouse. The next spring the shoots of these plants were severely infected with mosaic. Although these infected perennials occur in Maryland fields, our field survey did not show definitely that mosaic was more abundant near them.

The mosaic also passes thru the winter on susceptible plants in the greenhouse and may be carried from these to the field.

Another probable means of overwintering of the mosaic virus in Maryland is in hold-over virulent aphids.

## CONTROL OF MOSAIC

Control measures against mosaic should be directed toward the disease in the seed-bed, during the process of transplanting, in the field during the first part of the season, and in the greenhouse.

**In the Seed-Bed:** Mosaic can be controlled in the seed-bed by rogueing out mosaic plants and also the plants surrounding them. Keep down the weeds and eradicate any horse nettle or ground cherry plants that appear in or around the seed-bed. Do not chew tobacco while working in the seed-bed or otherwise contaminate the beds with old tobacco or anything that has come in contact with the mosaic. Thoroughly wash the hands with soap and water before working in the seed-bed.

**During Transplanting:** A large percentage of early mosaic infection in the field is due to the mosaic being brought in on the transplants. Only use transplants from mosaic-free seed-beds. Do not transplant weak, small, or off-color plants. Wash the hands frequently with soap and water (3) during the transplanting process.

Three experiments were conducted in the greenhouse to try out various control measures against the spread of mosaic in transplanting. While the plants were quite young, several of them were inoculated. When the plants had reached transplanting size a mosaic plant was pulled, the hands were treated and then several healthy plants were pulled and transplanted. Four different treatments of the hands were used: washing with soap and water, rubbing with dust, covering with mud, and allowing the virus sap to dry on the hands for various lengths of time. The controls consisted of plants that were pulled and transplanted where no treatment was given to the hands after pulling a mosaic plant. The results are presented in the following table.

TABLE 28. DATA AND RESULTS ON THE CONTROL OF MOSAIC DURING TRANSPLANTING

| Date of Transplanting | No. of Mosaic Plants Pulled | Treatment of Hands After Pulling | Healthy Plts. Pulled After Treatment | No. of Plants Mosaic | Per Cent of Plants Mosaic |
|---|---|---|---|---|---|
| | | | | 1-29-31 | |
| 1-13-31 | 1 | None | 6 | 4 | 66.7 |
| " | 1 | " | 6 | 6 | 100.0 |
| " | 1 | " | 6 | 5 | 83.3 |
| " | 1 | Washing | 6 | 0 | 00.0 |
| " | 1 | Dusting | 6 | 2 | 33.3 |
| " | 1 | Muddying | 6 | 2 | 33.3 |
| " | 1 | Dried (15 min.) | 6 | 6 | 100.0 |
| | | | | 3-5-31 | |
| 2-17-31 | 1 | None | 5 | 3* | 75.0 |
| " | 1 | " | 5 | 5 | 100.0 |
| " | 1 | Washing | 5 | 0 | 00.0 |
| " | 1 | " | 5 | 0 | 00.0 |
| " | 1 | Dusting | 5 | 0 | 00.0 |
| " | 1 | Muddying | 5 | 2 | 40.0 |
| " | 1 | Dried (30 min.) | 5 | 0 | 00.0 |
| | | | | 3-29-31 | |
| 3-13-31 | 1 | None | 5 | 5 | 100.0 |
| " | 1 | Washing | 5 | 1 | 20.0 |
| " | 1 | Dusting | 5 | 5 | 100.0 |
| " | 1 | Muddying | 5 | 2 | 40.0 |
| " | 1 | Dried (20 min.) | 5 | 5 | 100.0 |

* One plant died after transplanting.

The results of these experiments show that washing the hands with soap and water will insure against the spread of mosaic, and that dusting and muddying the hands will reduce the spread to some degree.

**In the Field:** If mosaic plants are noticed in the field during the first part of the season they should be rogued out and destroyed. If they are left in the field the mosaic will be spread from them to the healthy plants. Care should be taken during the first few cultivations to prevent touching the plants as experiments have shown that mosaic is spread in this way. Perennial weeds such as the horse nettle and ground cherries should be kept down. Do not plant tomatoes on the same ground every year.

**In the Greenhouse:** Tomato, tobacco, potato, pepper, petunia, nightshade, horse nettle, ground cherry, and related plants are mosaic carriers. Fumigate with nicotine sulphate to destroy the plant lice. If mosaic is present in the plants being grown its spread can be reduced by handling the healthy plants before the mosaic plants are handled. Avoid bruising the plants during the cultural operations. Greenhouse loss from mosaic is less than in the open and protection from it is less necessary, except that greenhouse mosaic is an important danger to outdoor beds and fields.

## SUMMARY OF EXPERIMENTAL DATA

1. Leaf-abnormality symptoms were produced by young plants inoculated with ordinary tobacco mosaic virus during periods of short day length and low light intensity. Plants above the third leaf stage never produced "fern-leaf" symptoms. Plants of the same age inoculated with cucumber mosaic virus rarely exhibited leaf-abnormality symptoms under the same conditions.

2. Attempts to infect tomato seeds, and the hypocotyls of tomato seedlings before chlorophyll was thoroly developed, were unsuccessful.

3. Three field and four greenhouse experiments were carried out to determine the correlation of the spread of mosaic with cultural operations. The results obtained show that mosaic is spread in the field during cultivation and in the greenhouse when the plants are tied up or pruned. The results also show that when care is taken in the cultural processes the spread of mosaic can be controlled to a great extent.

4. The results obtained in three field experiments conducted to determine the influence of the time of mosaic infection on yield show that the early infections reduced the yield much more than late infections.

5. One greenhouse experiment was conducted to determine the effect of mosaic on yield. The results obtained show that mosaic has little effect on the yield of plants grown under optimum greenhouse conditions.

6. A preliminary test was made on the effect of the mosaic disease on the canning quality of the fruit. The resulting scores were practically identical for the healthy and mosaic cans.

7. The results of three experiments carried out on drying healthy and mosaic leaves show that the mosaic leaves lose their water at a faster rate than healthy leaves.

8. Results obtained by the method of standardized hygrometric paper readings show that mosaic leaves transpire at a faster rate than healthy leaves.

9. The results of experiments on plants growing in nutrient solution show that long-diseased plants transpire more per gram dry weight and per square inch of leaf area than healthy plants. Coincidental with the appearance of mosaic symptoms there is a pronounced drop in the transpiration of infected plants. After this initial drop the transpiration gradually increases in diseased plants.

10. The green weight and dry weight of the tops and roots of long-diseased plants, and the leaf area, is materially reduced in comparison to healthy plants. During its incubation period in the plant the virus has no pronounced effect on the green and dry weight of the tops and roots.

11. The results obtained in 3 experiments that were carried out to test the efficiency of 4 methods of treating the hands to control the spread of mosaic after a diseased plant had been handled, show that washing the hands with soap and water will insure against the spread of mosaic, and that dusting and muddying the hands will reduce the spread to some degree.

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See Phytopathological Abstracts, Phytopathology, 23: 15, 26. 1933, for abstracts of some of the work herein reported.

# PART II.
# FUSARIUM WILT OF TOMATOES

J. B. S. NORTON.

This disease was found to be severe in some Eastern Shore fields in Maryland in 1910(1). It may have been present long before, but not separated from the bacterial wilt, recognized since 1895. The fungus, *Fusarium lycopersici*, causing the disease was described by Saccardo from Italy in 1882, as a variety of *F. oxysporum*. The disease it causes was noted in England in 1896, and it has been reported and worked on in the United States, at least since 1900 (2, 3, 4).

Tomato plants with this disease are usually first noticed in the field after fruit begins to develop, though plants sometimes die of it even before blooming. Scattered plants, usually more abundant in certain parts of the field, are retarded in growth, and the lower leaves yellowing. On lighter soils and in hot, dry weather the leaves wilt and the whole plant often dies long before nearby healthy ones. The disease is often worse on land that has been too wet, but may be longer delayed when there is a continued adequate supply of water.

An important diagnostic symptom is seen by cutting across the stem, showing the darkened woody ring while the outer part and center of the stem may still be green.

The yield of fruit is cut down, according to the percentage of plants infected, to 50% or more. This disease is also an important factor in greenhouse tomato production but is easily controlled by soil sterilization.

The parasitic fungus may live in the field for several years, without a tomato crop, though even one year's rotation reduces it some. Even 10 years may not free the soil of it entirely. The optimum temperature for the fungus is about 85 F. It seems to develop better in warm, light soils, which are somewhat acid. The association of this disease with local soil conditions is well shown by its rare appearance on our Station farm, though infected plants were used in fields from 1912-1915. The fungus enters through the small roots, which are often killed. It grows through the woody tissue of root, stem, and fruit, even out into the seeds. Infected plants in the beds and seeds from diseased plants are important means of spreading the disease to new fields.

A survey of the distribution of fusarium wilt in Maryland was made in 1927 and succeeding years. A map showing the results was published in Bulletin 318. The disease was most abundant

in the parts of the Coastal Plain where tomatoes have been most intensively produced, but even there some fields were without it and at least a few fields with fusarium infected plants were found as far west as Washington County.

In many fields in the central part of the Eastern Shore, where the disease was the worst, most of the plants were dead before the picking season was half over.

The internal infection taking place underground makes spraying impractical for this disease. Rotations are of more value the longer the land is without tomatoes. Seeds and plants from land where the disease is present should not be used on disease free land.

The successful production of varieties of other crops resistant to fusariums causing wilts and other diseases, indicated a probability of similar success with tomato varieties. The development of highly resistant tomatoes of the Beauty type was announced in Tennessee by Essery in 1912 (5), and Edgerton produced a resistant Acme in Louisiana (6).

Work on securing wilt resistant tomatoes for Maryland canning crops was begun in 1912 by planting a number of tomato varieties on land at Preston in which a tomato crop had been badly infected in 1910. This test showed (7) several varieties to be somewhat resistant to the wilt fungus. One of these was Duke of York. The common canning varieties then grown, especially Greater Baltimore, proved to be rather susceptible.

As we were more interested in the canning types, a more promising method seemed to be to select for breeding purposes, the best individual plants from badly diseased fields. This was done in September, 1912, and included, with seed from plants in fields at Vienna, Stevensville, Preston, Bethlehem and elsewhere, the better selections from the variety test mentioned.

Pedigree records of the best of these selections, tried the next year at Preston, were kept in 1913-1915, in the summer on a field which was abundantly planted with cultures of *Fusarium lycopersici*, and in winter in the greenhouse, thus getting two generations a year. Selection was made each generation for form of fruit, fusarium resistance, and especially for yield.

Some of the most promising selections were sent out to tomato farmers. One of the recipients of these select seeds was O. W. Twilley of Hurlock, Md., who maintained them for several years with continued selection and production of seed for sale, especially of the Wilt Resistant Greater Baltimore.

In 1915 F. J. Prichard, beginning tomato breeding for the U. S. Department of Agriculture, was given some of the best of these strains. One of these was a fine form of canning type, somewhat like Stone, which came from a field of mixed varieties

near Vienna, Md., in 1912. From this Prichard selected the variety which was put out by the U. S. D. A. under the name Norton. One of the others of best form, yield and resistance, was of Greater Baltimore parentage. Seeds of this stock were also given to Prichard for trial. In addition to the Norton variety, two of Prichard's resistant varieties of Greater Baltimore type, Columbia and Arlington, were named and disseminated.

These wilt resistant tomatoes, both from Maryland grown seed and from U. S. D. A. sources, were used extensively for several years by the Extension pathologists and tomato specialists of the University of Maryland in improving the Maryland tomato crop on fusarium infested land.

These and other desirable varieties, both wilt resistant and not, were used in an Extension test on tomato farms in several parts of the State, 1926 to 1928, and compared for yield and other desirable qualities as well as for wilt resistance when grown in fusarium infested regions. A report on these tests was made by Geise in Bulletin 318 (8). In these tests Marglobe, a later developed variety of Prichard, was found to be the best yielder, at least on wilt infested land and was a very satisfactory canning variety in other respects.

The Norton variety is a parent of Kanora, a successful wilt resistant variety developed at the Kansas Experiment Station. Illinois Experiment Station Bulletin 361, 1930, records the breeding of greenhouse tomatoes resistant to wilt.

These fusarium resistant varieties are in no sense immune to the fungus attack, but often show the browned wood due to its presence in the stem, yet give a satisfactory crop, much above the best ordinary varieties on the same infested fields.

Since 1929 the work has been continued in further selection and improvement of fusarium resistance in the better varieties for different purposes, but none are yet ready for introduction.

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# PART III.

# TOMATO DISEASES AND THEIR CONTROL

J. B. S. Norton and H. A. Hunter.

Under this title a brief guide to the more noteworthy tomato diseases is given. In many cases other publications, mostly Experiment Station bulletins, are mentioned, where a more complete account of a disease can be found. Many other papers on tomato diseases have been made use of in order to bring together in a small compass most of the available information which will aid in keeping tomatoes in a healthy and productive condition. Advice on general treatment is given at the end.

## DISEASES OF YOUNG PLANTS

Many later troubles start with the young seedlings, but may not be noticed till fruiting time. The familiar damping-off of plants is due to several different fungi growing from the ground into and killing the young stems, and is favored by dampness among crowded plants. A little drying then causes the injured plants to collapse.

Many parasitic fungi live over on, or near, the soil surface, where the infected remains of previous crops fell, or where they are carried by winds and rains. From this source, a few spots on the small leaves and stem, may start the parasites, which develop weeks later into an epidemic. Concentrations of soil salts, blowing sand, and other causes of injury near the ground surface favor parasitic attack at this point. *Macrosporium solani* and *Rhizoctonia solani* are the most common foot-rot or collar-rot fungi. For damping-off, see New York Bulletins 586, 1930; and 615, 1932. For collar-rot see Journal Agricultural Research 21: 179-184, 1921.

The main secret of a profitable crop often lies in keeping the plants, from seed to blossom, growing strong and hardy, without any checking of growth.

## ROOT DISEASES

The nematode, *Caconema radiciola,* the cause of root knot on many crops further south, sometimes appears in Maryland tomato fields. It is a frequent cause of injury in greenhouses or in plant beds where the soil has not been frozen deeply. Soil sterilization is the best greenhouse treatment. Another nematode, *Tylenchus pratensis,* causing less noticeable root injury, is to be looked for in Maryland.

*Sclerotium rolfsii,* causing a destructive root disease in the Southern States, was found as far north as Washington in 1931, but is not expected to become important in Maryland. The common Sclerotinia of herbaceous plants sometimes kills greenhouse tomatoes.

## DISEASES OF STEM AND WHOLE PLANT

The lack of necessary elements in the soil is usually expressed in reduced growth, as well as in characteristic leaf symptoms for the different chemicals. Such diseases are well described for a related crop, tobacco, by McMurtrey, U. S. D. A. Technical Bul. 340, 1933, with a colored plate of the various symptoms.

Too much soluble fertilizer or other salts in the soil may cause stunting and dark green color.

Tomatoes are not seriously injured by considerable variation in soil acidity. Kentucky Bulletin 314, 1931, records the results with tomatoes on soils of various reactions.

Circular areas a few yards across, where all the plants are dead or nearly so, are occasionally seen where lightning has struck a field.

Forced growth and very moist air in greenhouses sometimes causes a mealy growth of enlarged cells on tomato stem and leaves, which is known as oedema.

The fusarium wilt and mosaic disease, treated in another part of this Bulletin, are the leading stem and whole plant diseases. The bacterial wilt, due to *Bacillus solanacearum,* growing in the vascular tissues of the stem, is much less common. A verticillium is sometimes found in the stem and causes a disease similar to the fusarium wilt. A virus disease, streak, causing small, dead stripes on stem and leaves, is sometimes seen, especially in greenhouses, and seriously affects all parts of the plant. It is worse on very fertile heavy soils. Bacterial canker causes a wilting of the leaves without any appreciable wilting of the branches. Under certain conditions longitudinal cankers appear on the stems. See Journal Agricultural Research 41: 825-851, 1930.

## LEAF DISEASES

Diseases which injure the water conducting tissues of the stem are usually first noticed in the wilted or discolored leaves. The lower leaves are generally the first to turn yellow or brown and die, whether from natural causes, or from some of the systemic diseases, or from leaf spots caused by parasites. The mosaic disease shows itself chiefly in the mottled or sometimes deformed leaves. The bacterial wilt often shows first as a wilting of the ends of young branches.

The most common of all diseased conditions noticed on tomatoes is what is usually called blight, and is a complex of leaf injuries by hot, dry weather and two leaf spot producing fungi, *Macrosporium solani* and *Septoria lycopersici,* sometimes one or the other predominating. The older macrosporium spots usually show somewhat concentric lines. The septoria spots have a dark border around a gray center with minute dark dots. Both, especially the macrosporium, occur also on potatoes and related plants. See Virginia Truck Station Bulletin 59, 1927.

The macrosporium spots on potato have been called early blight, to distinguish the disease from the destructive late blight due to *Phytophthora infestans,* which fungus also sometimes attacks tomatoes and may be expected in cool damp weather in the higher parts of Maryland.

The septoria leaf spot is often quite destructive in seasons of frequent rains, and can reduce the tomato foliage to only a bunch of young leaves on the stem tips, leaving the stunted fruits to imperfectly ripen and sunburn. This fungus apparently almost disappeared from Maryland during recent dry years but was becoming abundant in 1932 in some fields, and where no apparent damage was done it could be recovered by inoculations made from dead leaves.

Leaf mold, due to the fungus *Cladosporium fulvum,* sometimes occurs in the field here, usually being carried out on greenhouse-grown plants. It is the most destructive greenhouse tomato disease, and controlled with difficulty. Some varieties are more resistant to it. See Massachusetts Bulletin 248, 1929.

An upward rolling of tomato leaves, when they are getting insufficient water, is so common as to be a characteristic of some varieties.

Tomatoes are very easily injured by frost. The effects of protection from frost are treated in Michigan Technical Bulletin 124, 1932; see also U. S. D. A. Bulletin 1090, 1922.

Some diseases not yet reported from Maryland are: Curly top or Western yellow blight, a virus disease in the Western states; Psyllid yellows, another Western virus disease, more common on potatoes; Australian blight or spotted wilt (see Journal Dept. Agric. West Australia 5: 58, 1928); gray leaf spot, caused by *Stemphylium solani,* an important disease in Florida (see Florida Bulletin 249, 1932).

Virginia Truck Experiment Station Bulletins 33 and 34, 1921, and 46, 1924, deal with spraying and dusting tomatoes. Ohio Bimonthly Bulletin for January, February, 1933, reports some detrimental effects of spraying tomatoes with bordeaux mixture.

## FRUIT DISEASES

Many species of fungi and bacteria grow in tomato fruits, causing rots or external spots. The rot organisms very often enter growth cracks or insect punctures, and injuries from hail, blowing sand, handling, etc. The common black mold, *Rhizopus nigricans*, and the soft rot bacteria often occur in rotting fruits. A form of the common, bad smelling white mold, so abundant around canning factories, *Oidium lactis*, rots enormous quantities of tomato fruits. See Phytopathology 14: 460-477, 1924; Journal Agricultural Research 24: 895-905, 1923, and 33: 1009-1024, 1926.

Blossom end rot appears as a dead, often black, mold covered spot on the tip of green or prematurely ripened fruits. It is associated with lack of sufficient water to keep the whole fruit alive, and is generally seen in the hotter summer weather when vigorously growing plants have suddenly become too dry. It frequently follows root cutting by too deep cultivation and is frequent when stem diseases cut off the water supply. Marglobe is less subject to blossom end rot than is Greater Baltimore or Stone.

Anthracnose *(Colletotrichum phomoides)* is frequent as slightly sunken circular spots, especially in late summer, and often decays quantities of over-ripe fruit after picking.

Bacterial spot, due to *Bacterium vesicatorium*, is seen as small, depressed, dark spots on fruit. It caused considerable damage in some Maryland fields in 1932. See Indiana Bulletin 251, 1921, and Phytopathology 13: 307-315, 1923.

Bacterial canker, caused by *Aplanobacter michiganense*, shows as small brown spots with light borders on the green fruit. It occurred in a few fields in Maryland in 1932, from southern plants or infected seed. See U. S. D. A. Circular 29, 1928.

Tomatoes resting on the ground are easily attacked by rot fungi. *Phytophthera terrestris* causes the buckeye rot, and *Corticium vagum*, more familiar as rhizoctonia, produces a similar decay known as soil rot. See Phytopathology 7: 119-129, 1917.

Nailhead spot, chiefly troublesome on tomatoes shipped from the South, is due to *Macrosporium tomato*. See U. S. D. A. Yearbook 1927: 630-633, and Journal Agricultural Research 38: 131-146, 1929.

Black spot due to *Phoma destructiva* mars and slowly rots even green fruit, especially in transit. See U. S. D. A. Circular 219, 1922.

Sun scald on the more exposed side of fruits is a frequent injury on tomatoes with little foliage. It causes loss of quality, and rot fungi enter the injury.

An internal hard spot of the fruit, reported from some parts of the United States, seems to be associated with hot weather injury. See Plant Disease Reporter 14: 208, 216, 1930.

Many malformations such as catface, ridged and grooved fruits, growth cracks, and other undesirable conditions of fruit are due to hereditary causes or to soil and climate variations.

U. S. D. A. Miscellaneous Publication 121, 1932, gives a very useful account of diseases found on market tomatoes, with illustrations of many in natural color.

## GENERAL RECOMMENDATIONS FOR TOMATO DISEASE CONTROL

1. Rotate, with tomatoes several years apart. Fall plowing the land will aid in preventing leaf blight and other diseases that live over in waste on the surface. The soil should be nearly neutral, not too light, and of good fertility.

2. Use the best selected seed, as nearly as possible free from disease, and of the best yielding, disease resistant varieties suitable for the purpose for which the variety is grown.

3. The seed bed should be in a new, fall plowed location each year, or preferably, the plants grown under protection. The soil should be kept free from tomato or tobacco or related plants and weeds, or other disease carrying material. The seed may be treated just before planting with a reliable disinfectant.

4. Spray the plants in the beds weekly with bordeaux or dust with copper-lime dust and an arsenical. Irrigate if the weather is dry.

5. Be careful in pulling and setting plants, as these operations give the greatest chance of loss from mosaic disease and other troubles spread by contact. Set the strongest, healthiest plants, in weather as suitable as possible to prevent wilting and favor rooting, and as early in the season as practicable.

6. Cultivate frequently. At the first cultivation, pull out mosaic plants and avoid touching others. The later cultivations should be shallow.

7. Do not pick diseased fruits. They spoil the market and spread disease.

8. Greenhouse plants should be grown in a disease free house, sprayed and fumigated for disease and insects and planted in new or sterilized soil; using wilt and leaf mold resistant varieties. In setting plants avoid contact with infection and pull out diseased plants found in the next two weeks.